The value of 0·0077 gramme that we have adopted for assimilation in the open air when the CO_2-pressure is the limiting factor, was obtained by Brown and Morris by this method, and is therefore subject to suspicion and is probably too high.

The new data for arriving at this most important value, brought forward by Brown and Escombe, and based on measuring the intake of CO_2 by a leaf in a glass chamber in a rapid current of ordinary air, show a very wide range of variation even for the leaves of a single species (0·0016 to 0·0047 gramme per 50 sq. cm. for *Polygonum Weyrichii*). Primarily, the degree to which the stomata are open and, secondarily, the magnitude of the concurrent respiratory production of CO_2, would seem to be the important factors in disturbing the inflow of CO_2 from without.

The highest value thus arrived at is 0·0047 for a detached leaf, and as attached leaves with stomata less widely open give smaller values, the number adopted by us may be much too high. This would increase the waste of photosynthetic radiation in Nature, but the information at present available is not sufficient to allow us to readjust the table on p. 455].

Note on the Mechanics of the Ascent of Sap in Trees.

By Professor J. Larmor, Sec. R.S.

(Received June 29, 1905.)

The following remarks, relating to one of the most powerful and universal of the mechanical operations of organic nature, are based mainly on the numerous experimental results reported in Dr. A. J. Ewart's recent memoir.* Their chief object is to assert the view that we are not compelled to suppose the sap, in the column of vessels through which it rises, to be subject to the great actual pressure, amounting in high trees to many atmospheres, that is sometimes postulated. It is hardly necessary to remark that the problem of the rise of sap is one of mechanics, in so far as concerns the mode of the flow and the propelling power.

Contrary to the view above referred to, it seems not unreasonable to consider that the weight of the sap in each vessel is sustained in the main by the walls and base of that vessel, instead of being transmitted through its osmotically porous base to the vessels beneath it, and thus accumulated as hydrostatic pressure.

We could in fact imagine, diagrammatically (as happens in ordinary osmotic arrangements) a vertical column of vessels, each provided, say, with a short vertical side-tube communicating with the open air, in which the pressure is adjusted from moment to moment, and yet such that the sap slowly travels by transpiration from each vessel to the one next above,

* 'Roy. Soc. Proc.,' vol. 74, p. 554 ; 'Phil. Trans.,' B, vol. 198, p. 41.

through the porous partitions between them; provided there is an upward osmotic gradient, *i.e.*, if the dissolved substances are maintained in greater concentration in the higher vessels.* This difference of density must be great enough, between adjacent vessels, to introduce osmotic pressure in excess of that required to balance the head of fluid in the length of the upper one, into which the water has to force its way. Thus, in comparing vessels at different levels, the sap must be more concentrated in the upper ones by amounts corresponding to osmotic pressure more than counteracting the total head due to difference of levels, in order that it may be able to rise. As osmotic pressure is comparable with gaseous pressure for the same density of the molecules of the dissolved substance, the concentration required on this view is considerable, though not very great.

Such a steady gradient of concentration could apparently, on the whole, become self-adjusting, through assistance from the vital stimuli of the plant; for concentration in the upper vessels is promoted by evaporation. Yet pressures in excess or defect of the normal atmospheric amount might at times accumulate locally, the latter giving rise to the bubbles observed in the vessels, through release of dissolved gases.

It may be that this assumes too much concentration of dissolved material in the sap, *as it exists inside the vessels of the stem,* to agree with fact. In that case the capillary suction exerted from the nearest leaf surface might be brought into requisition, after the manner of Dixon and Joly, to assist in drawing off the excess of water from the vessels. The aim proposed in this note is not to explain how things happen, which is a matter for observation and experiment, but merely to support the position that nothing abnormal from the passive mechanical point of view need be involved in this or other vital phenomena.

* Thus in an ordinary osmotic experiment with a U-tube, the percolation of water through the plug gradually *produces* a difference of hydrostatic pressure on its two faces, which is *sustained* by the fixity of the plug itself, but would be at once neutralised if the plug were free to slide in the tube. This increase of volume of the salt-solution, by the percolation of pure water into it, is on the van't Hoff analogy correlated with the free expansion of the molecules constituting a gas. It goes on with diminished speed under opposing pressure, until a definite neutralising pressure is reached, inaptly called the osmotic pressure of the molecules of the solute, which just stops it, while higher pressures would reverse it. The stoppage is due to the establishment of a balance between the amounts of water percolating one way under osmotic attraction, and the opposite way under hydrostatic pressure. The pressure established, *e.g.*, in an organic cell immersed in salt-solution, is thus really the reaction which is set up against the osmotic process. That process itself is perhaps more directly and intelligibly described as the play of osmotic affinity or attraction, even though it must be counted as of the same nature as the affinity of a gas for a vacuum. *Cf.* 'Proc. Camb. Phil. Soc.,' January, 1897, or Whetham's "Theory of Solution," p. 109.

As regards estimating the amount of flow, at first sight it may not appear obvious, *a priori*, that the transpiration through a porous partition or membrane, due to osmotic gradient, is equal or even comparable in amount to what would be produced, with pure water, by a hydrostatic pressure-head equal to the difference of the osmotic pressures on the two faces of the partition. But more exact consideration shows that on the contrary osmotic pressure is *defined* by this very equality;* it is that pressure-difference which would produce such an opposite percolation of water as would just balance the direct percolation due to the osmotic attraction of the salt solution.

It would, however, appear that the great resistance to flow offered by what botanists call Jamin-tubes, viz., thin liquid columns containing and carrying along numerous broad air-bubbles, is conditioned mainly by the viscosity of the fluid, and involves only indirectly the surface-tension of the bubbles. In fact the resistance to flow may be expected to remain much the same if each bubble were replaced by a flat solid disc, nearly but not quite fitting the tube. Its high value arises from the circumstance that the mass of liquid between two discs moves on nearly as a solid block when the flow is steady, so that the viscous sliding has to take place in a thin layer close to the wall of the tube, and is on that account the more intense, and the friction against the tube the greater. The increased curvature of the upper capillary meniscus of the bubble is thus merely a gauge of the greater intensity of the viscous resistance instead of its cause, and modification of the surface-tension cannot be involved as a propelling power. The experimental numbers given by Dr. Ewart show that, even where the vessels are largely occupied by bubbles, the greater part of the resistance to active transpiration still resides in the partitions between them.

If the osmotic gradient, assisted possibly by capillary pull at the leaf-orifices, is insufficient to direct a current of transpiration upward, *capillary* alterations inside the vessels, arising from vitally controlled emission and absorption of material from the walls, cannot be invoked to assist: rather it must be *osmotic* alterations from one vessel to the next, of, so to speak, a peristaltic character, that might thus come into play. But any such alteration (of either kind) will involve local supply of energy. Is there a sufficient fund of energy, latent in the stem, to provide permanently the motive power for the elevation of the sap? In what form could this energy get transported there? The energies of the plant-economy come from the sunlight absorbed by the leaves. The natural view would appear to be that the work required to lift the sap is exerted at the place where the energy is received, and that it operates through extrusion of water by evaporative processes working

* See preceding footnote.

against the osmotic attraction of the dissolved salts; while the maintenance of equilibrium along the vessels of the balanced osmotic column, with its semi-permeable partitions, demands that an equal amount of water must rise spontaneously to take the place of what is thus removed.

The subject might, perhaps, be further elucidated by observation of the manner in which the flow is first established at the beginning of the season, or possibly by experiments on the rate at which water would be absorbed by a wounded stem high above the ground.

On the Cytology of Apogamy and Apospory.—II. Preliminary Note on Apospory.

By Miss L. Digby.

(Communicated by Professor J. B. Farmer, F.R.S. Received April 15,—Read May 11, 1905.)

Apospory is the direct vegetative process which leads from the sporophyte to the gametophyte without the intervention of spores. This phenomenon has for a long time been known to occur in mosses* and ferns,† and several writers have described its morphological characters, but its cytological history has hitherto remained unrecorded. In a previous note‡ the cellular features of apogamy were briefly described, and it is here proposed to treat the problem of apospory in a similar manner. The following remarks are limited to the study of apospory in *Nephrodium pseudo-mas* Rich. var. *cristata apospora*, Druery,§ but it is of interest to note that within the limits of a (probably) single, but highly variable species, almost all grades of apospory and

* N. Pringsheim, "Vegetative Sprossung der Moosfrüchte," 'Monatsb. Akad. Wiss., Berlin,' July 10, 1876, pp. 425 to 429.

E. Stahl, "Ueber künstlich hervorgerufene Protonema-bildung an dem Sporogonium der Laubmoose," 'Bot. Zeitg.,' vol. 34, 1876, pp. 689 to 695.

N. Pringsheim, "Ueber Sprossung der Moosfrüchte und den Generationwechsel der Thallophyten," 'Jahrb. für wiss. Bot.,' vol. 11, 1878, pp. 1 to 46.

† C. T. Druery, "Observations on a Singular Mode of Development in the Lady Fern (*Athyrium Filix-fœmina*)," 'Jour. Linn. Soc. Bot.,' vol. 21, 1884, pp. 354 to 358 and pp. 358 to 360.

F. O. Bower, "Apospory and Allied Phenomena," 'Trans. Linn. Soc. Bot.,' 2nd series, vol. 2, Part 14, July, 1887, pp. 301 to 326.

‡ J. B. Farmer, J. E. S. Moore, and L. Digby, "Preliminary Note on Apogamy," 'Roy. Soc. Proc.,' vol. 71, 1903, pp. 453 to 457.

§ See "*Lastrea pseudo-mas* var. *cristata apospora*," C. T. Druery, 'Book of British Ferns,' p. 99.